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Environmental Protection Branch

Report No. 213

PRESSURE EXERTED BY PACK STRAPS AS RELATED TO LOAD CARRIED AND CHEST DIMENSIONS

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PRESSURE EXERTED BY PACK STRAPS AS RELATED TO LOAD CARRIED AND CHEST DIMENSIONS

ABSTRACT

Purpose: To measure objectively the pressure exerted on various parts of the shoulders and chest by pack straps, and to find out the relationship between strap pressure and chest size.

Summary: A special pressure meter was devised to measure strap pressure. It consists of a sphygmomanometer in which the rubber cuff has been replaced by a rubber tube. Strap pressure was tested on 39 male subjects who carried high or low packs weighing from 20 to 70 pounds while standing still on horizontal, downgrade, or upgrade planes, or walking on the same planes. A mathematical relationship between strap pressure and pack weight was established and formulas derived for determining strap pressure in pounds while standing or walking when pack weight was known. In standing, the strap pressure is greater at the top than at the front of the shoulders. For a 40-pound pack, these pressures are 6 and 4.4 pounds, and for a 70-pound pack, they are 10.5 and 7.4 pounds, respectively. During walking, the pressure increases. For a 40-pound pack it becomes 9.6 and 6.3 pounds, and for a 70-pound pack, 15.5 and 10.0 pounds. The relation between strap pressure and the chest size was studied on 49 men. It was found that the larger the chest, the greater the pressure on the shoulder front and the smaller the pressure on the shoulder top.

Conclusions: The pressure meter is a reliable instrument with an objectivity coefficient of .93 during measurements when the subject is standing, and .96 when the subject is walking. By means of this meter, the probable degree of comfort or discomfort of a newly designed pack may be objectively measured. The meter can be used very easily, will give reliable information, and will save time.

Recommendation: That the pressure meter described in this report be used on new designs of packs before a field study is undertaken.

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FOREWORD

Many factors operate in the interaction of a man and his packload - the force of gravity, moments of force resulting from the relative location of the center of gravity of the body and the center of gravity of the load, acceleration and deceleration of the load and parts of the body during walking. All of these forces obviously impinge upon the man as a local pressure at one or many points on his body surface.

Pack carriers, particularly before conditioning or hardening, may complain bitterly of pressure on the shoulders as the limiting factor in tolerance to the load, to the point where some men may have compression of the subclavian artery leading to interference with blood supply to the hands.

Dr. P.V. Karpovich in his work at Springfield College, under Contract No. DA44-109-qm-912, has developed a method for measuring pressure under shoulder straps which will be important in background studies of the principle of load-carrying and in testing of specific items of load-carrying equipment.

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PRESSURE EXERTED BY PACK STRAPS AS RELATED TO LOAD CARRIED AND CHEST DIMENSIONS

1. Introduction

a. The ideal pack for a soldier should allow freedom of movement, should weigh nothing, should be invisible, and yet should contain everything needed. This introductory statement represents a condensation of three philosophies: that of the man who carries the pack; that of the fighting commander; and that of the logistician. Moreover, this statement may serve as an overall guide to a person working on the problem of how to improve the pack.

b. The main source of discomfort and, therefore, of complaints regarding the pack is the pressure exerted by pack straps. The most common way of obtaining relief from this discomfort is temporarily to eliminate or shift the localization of pressure by placing the thumbs under the straps -- a device well known to every foot soldier. In spite of the important part played by strap pressure, no objective evaluation of this factor has ever been made.

c. The purpose of this study was to determine the amount of pack strap pressure exerted on various parts of the shoulders and chest, to find out the relationship between strap pressure and chest size, and to design an instrument and work out a method by which this information could be obtained. It is believed that the instrument described here will become a valuable help in testing new designs of packs.

2. Materials and Methods

a. Materials

For that part of the study which concerned the relation between strap pressure and pack weight, 37 male subjects were used. They ranged in age from 18 to 25 years, in height from 5' 5-1/2" to 6' 2", and in weight from 118 to 230 pounds. For the study of the relationship between strap pressure and chest size, 49 male subjects were used. These men ranged in age from 18 to 36 years, in height from 5' 4" to 6' 3", and in weight from 118 to 320 pounds.

Packs were made from Army five-gallon water cans strapped to a plywood packboard and filled with lead shot until the total weight was 20, 30, 40, 50, 60 or 70 pounds. The pack straps were two inches wide. Walking with the pack was done on a motor-driven treadmill maintained at a speed of 2.8 mph. Although only one end of the treadmill could be elevated, the motor could be reversed, so the subjects were able to walk upgrade and downgrade. To measure strap pressure, a special pressure meter was designed. Essentially, this consists of a sphygmomanometer set, in which the rubber cuff has been replaced by a piece of rubber tube acting as a pressure chamber. When this chamber is placed under a

Figure 1: Manikin Used in Preliminary Phase of Study

Note pressure chamber under pack strap for measuring pressure on top of shoulders

strap, the pressure exerted by the strap can be read on the sphygmomanometer.

Before the present meter was designed, other devices employing springs were tried. The electronic devices were purposely avoided because it was essential to have a simple and portable instrument. All preliminary work on strap pressure was done on male and female manikins (Figure 1) because prolonged standing caused dizziness and even fainting in human subjects.

1) <u>Construction of pressure meter</u>. The pressure chamber (Figure 2) consists of a piece of rubber tubing (A) four inches long, with a half-inch bore and a one-eighth-inch thick wall. Tubing of these particular dimensions was selected as most efficient after a series of experiments with various kinds and lengths of tubing.

Both ends of the chamber were plugged with rubber stoppers. One of the stoppers had a hole in the center through which a piece of metal tube, three inches long and one-fourth inch in diameter, was inserted. The pressure chamber was connected by thick-walled tubing (B) and (B_1) with a table model sphygmomanometer (C) and a compression rubber bulb (D). Tubing B and B_1 had a one-eighth-inch bore and a wall one-eighth inch in thickness. The length of B was about 20 inches, just long enough to be conveniently connected with the sphygmomanometer. The length of B_1 depended on experimental conditions. Since, in the present study, subjects walked on the treadmill and the sphygmomanometer was placed on a table at the level of the subject's feet, nine feet of tubing was required. If, on other occasions, the pressure meter were used while the subject walked on the ground and the investigator carrying the meter followed him, the length of the tubing would be reduced. The table model sphygmomanometer was selected because it combined portability with a sufficiently large dial to make reading easier.

2) <u>Calibration of pressure meter</u>. When a sphygmomanometer is used for blood pressure measurement, the air is pumped into the cuff until the flow of blood through the artery is stopped. It does not matter, therefore, if a small or a large manometer is used. When a sphygmomanometer is converted into a strap pressure meter, the principle

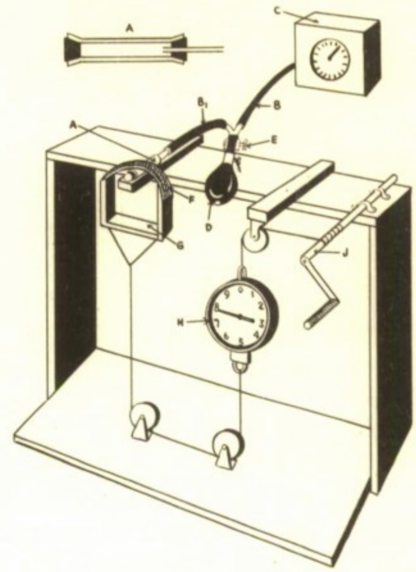

Figure 2: Pressure Meter and Device for Its Calibration

A - is the pressure chamber (details shown at A top) connected by means of rubber tubes (B) and (B_1) with a manometer (C) and a compression rubber bulb (D). For calibration, A is placed under a strap (F) attached to a yoke (G). By operating the windlass (J), a pressure of from one-half to 16 pounds in increments of one-half pound can be applied to the chamber. The amount of pressure will be indicated by the scale (H). From the recorded manometer readings and corresponding scale readings, the factor for converting millimeters into pounds will be obtained.

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of its use becomes different. The reading on the manometer will depend on the extent of the flattening of the pressure chamber caused by the pack strap. This flattening will reduce the total space of the pressure measuring unit; i.e., in the chamber, rubber tubing and the aneroid, causing a proportionate increase in the pressure of the air trapped in that space. The reading on the meter will, therefore, be affected by the length of rubber tubing and the size of the meter. It follows that each pressure meter should be calibrated so that millimeters of pressure on the dial can be translated into pounds of pressure exerted by the pack straps upon the chamber. Once this calibration has been done, the length or type of tubing or connecting parts should not be changed without re-calibration.

Calibration was done by means of a simple device shown in Figure 2. The pressure chamber (A) was placed on a wooden block. The pressure inside the chamber was raised by means of the rubber bulb (D) to 100 mm. and the clamp (E) was tightened to prevent leakage. The strap (F) of the yoke (G) was placed upon the chamber. The yoke was connected with a spring scale (H) and the latter was connected with the windlass (J). By operating the windlass, a desired pressure could be exerted upon the chamber. The pressure used for calibration ranged from one-half to 16 pounds, in increments of one-half pound. The manometer readings, corresponding to each pressure in pounds, were recorded and a conversion factor was determined.

Since the straps of the packs used in the present study were of two different widths -- two inches on the top of the shoulder and one inch on the front of the chest -- the pressure meter was calibrated for both widths. This means the strap (F) was two inches wide for one calibration and one inch wide for another calibration. The conversion factors thus obtained were: for the two-inch strap, .1964; for the one-inch

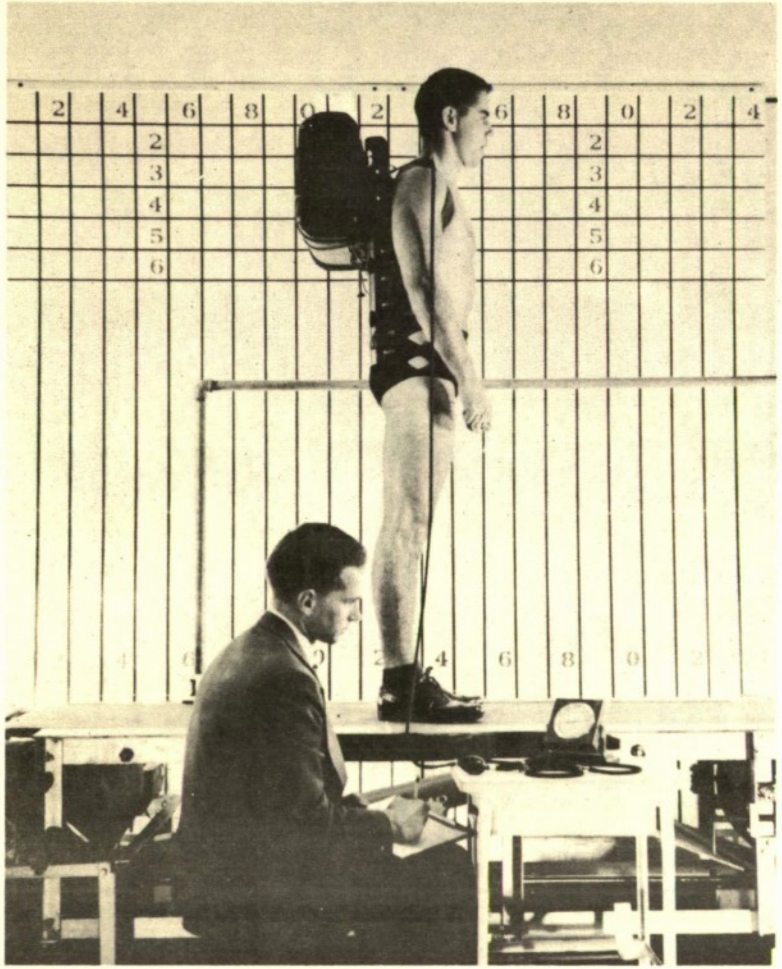


Figure 3: High Pack

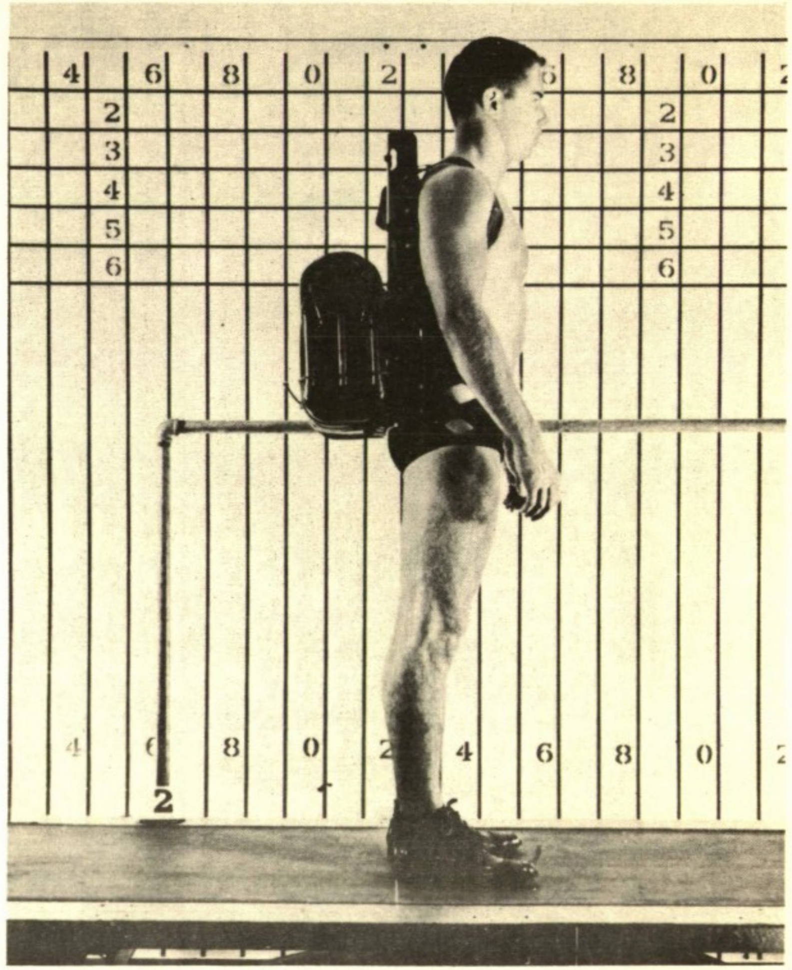


Figure 4: Low Pack

The upper part of the water can is at the level of the top of the packboard. Subject stands on a treadmill. Strap pressure is being measured at the shoulder top.

strap, .2610. Multiplication of the sphygmomanometer reading by these factors gave the strap pressure in pounds.

3) Objectivity of pressure measurement. Two investigators measured the strap pressure on 22 subjects during standing and walking, using the 40-pound pack. Each investigator went through the entire test, including putting on and adjusting the pack and placing the pressure meter under the strap. The coefficients of correlation for pressure and pack weight obtained during standing were "r" = +.93, and during walking "r" = +.96. These coefficients attest the high objectivity of the method.

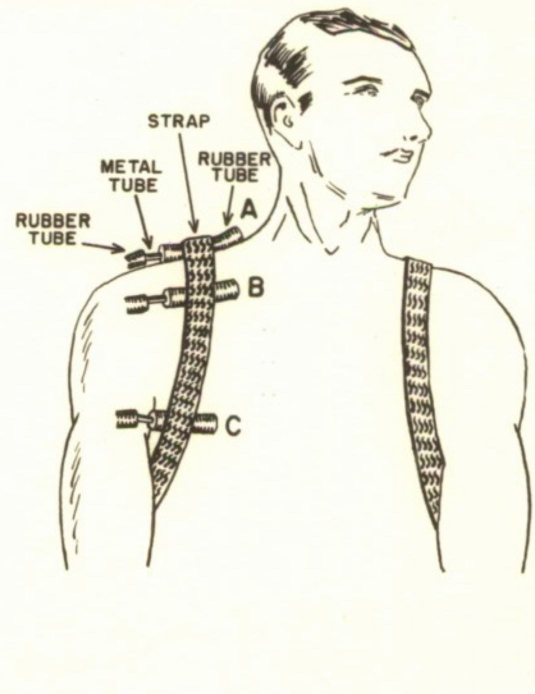
b. Methods

1) Strap pressure. Strap pressure was measured while the subjects were standing and during walking on horizontal, downgrade, and upgrade planes. Walking was done on a motor-driven treadmill maintained at a speed of 2.8 mph. The angle for downgrade and upgrade walking was nine degrees. Each subject was tested carrying a high and a low pack (Figures 3 and 4). In all, each subject was tested 36 times. For the high pack, the load was strapped to the packboard so that the top of the pack was in line with the top of the packboard. For the low pack, the bottom of the pack was in line with the bottom of the packboard. During walking, the subject was dressed in fatigue uniform and held his hands in his trousers pockets. This precaution was necessary because, when the arms swung forward, they caused a slight bend in the pressure chamber, which distorted the pressure record.

2) Pressure points. The points at which strap pressure was measured were: on the top of the shoulder (Figure 5), over the clavicle, and on the front of the shoulder at the tip of the front axillary fold. These points were selected because they are most frequently mentioned in complaints of discomfort caused by pack straps.

Figure 5: Points at Which Strap Pressure Is Measured

Legend A - Shoulder Top
B - Clavicle
C - Shoulder Front



3) Chest measurements. In order to determine whether strap pressure depended on chest size, certain anthropometric measurements of the chest were made. They were: a) chest circumference at the nipple level; b) lateral, and c) antero-posterior diameters, also at the nipple level; d) distance between the lateral borders of the acromial processes; and e) length of the sternum from the interclavicular notch to the xiphosternal articulation. In addition, the f) circumference of the right shoulder and g) the length of strap in contact with the body were also measured.* Extreme and average subject types are shown in Figure 6.

4) Technique for measuring shoulder circumference. With the right arm extended sideway to a horizontal position, a steel tape was placed against the armpit as close to the trunk as possible. When the subject lowered his arm to his side, the tape was brought across the acromial process and the circumference recorded.

5) Technique for measuring length of pack strap in contact with the body. Two metal sliding sleeves were placed on the right strap, one at the juncture of the strap with the bottom of the packboard, and the other where the strap joined the top of the packboard. Then each sleeve was moved upward toward each other until the pressure of the strap

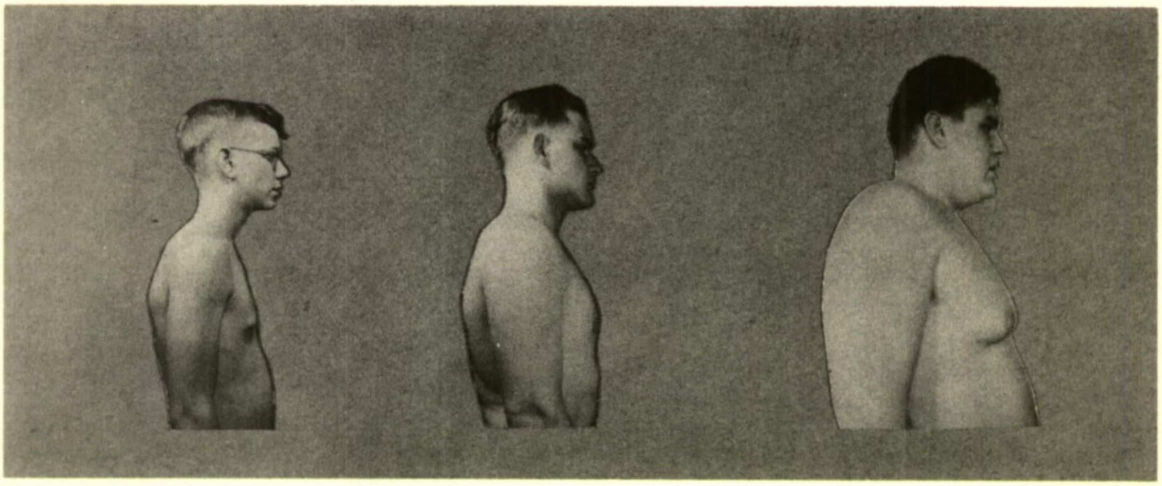


Figure 6: Types of Subjects Used in Anthropometric Phase of Study

*In the anthropometric study, the pressure points were measured while subjects stood still on a horizontal plane and while they walked on the horizontal. The speed of walking was 2.8 mph. The pack in every instance weighed 40 pounds.

against the body held the sleeve in a fixed position. Strap length between the proximal edges of the metal sleeves was then measured.

3. Results

a. Strap pressure in standing. It was found that pressures on the shoulder top and clavicle were equal. For this reason, the data obtained on clavicles are not presented here.

In Table I, the strap pressure on the top of the shoulder exerted by the low pack appears to be the same whether men stood on a horizontal plane or faced downgrade or upgrade. Analysis of the data substantiated this impression, because the differences in pressures for these various ways of standing were found to be not statistically significant (Table II). The same was found to be true for the high pack (Table III).

TABLE I: PRESSURE (in pounds) OF PACK STRAPS ON TOP OF SHOULDERS DURING STANDING

	Low Pack						High Pack					
On a Horizontal Plane												
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	3.0	4.4	5.9	7.4	8.7	10.0	3.3	4.8	5.8	7.3	8.3	9.7
Std. Deviation	1.4	1.4	1.8	2.2	2.5	2.9	1.1	.8	1.5	1.8	1.9	2.2
Std. Error of Mean	.2	.2	.3	.4	.4	.5	.2	.1	.3	.3	.3	.4
Facing Downgrade												
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	3.0	4.7	5.9	7.3	8.7	10.1	3.0	4.5	5.8	6.9	8.1	9.3
Std. Deviation	.9	1.1	1.3	1.6	1.9	1.9	.9	1.1	1.1	1.5	1.8	1.9
Std. Error of Mean	.1	.2	.2	.3	.3	.3	.1	.2	.2	.2	.3	.3
Facing Upgrade												
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	3.2	4.7	6.1	7.7	9.0	10.7	3.4	5.0	6.4	7.9	9.2	10.7
Std. Deviation	1.1	1.4	1.7	2.4	2.5	2.6	.9	1.3	1.5	1.9	2.1	2.7
Std. Error of Mean	.2	.2	.3	.4	.4	.4	.1	.2	.2	.3	.4	.4

COMPARISON OF PRESSURE EXERTED BY STRAPS OF LOW AND HIGH PACKS ON TOP OF SHOULDERS DURING STANDING ON A HORIZONTAL PLANE OR FACING UPGRADE OR DOWNGRADE ON AN INCLINED PLANE

TABLE II: LOW PACK

Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Down-grade
Upgrade			
20	D	.20	.20
	t	.69	.87
30	D	.30	.0
	t	.91	.0
40	D	.20	.20
	t	.49	.57
50	D	.30	.40
	t	.56	.83
60	D	.30	.30
	t	.52	.58
70	D	.70	.60
	t	1.08	1.11
Downgrade			
20	D	.0	
	t	.0	
30	D	.3	
	t	1.00	
40	D	.0	
	t	.0	
50	D	.10	
	t	.21	
60	D	.0	
	t	.0	
70	D	.10	
	t	.16	

TABLE III: HIGH PACK

Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Down-grade
Upgrade			
20	D	.20	.20
	t	.87	.95
30	D	.30	.0
	t	1.20	.0
40	D	.20	.20
	t	.57	.65
50	D	.60	.40
	t	1.36	1.00
60	D	.30	.30
	t	.63	.65
70	D	.70	.60
	t	1.21	1.09
Downgrade			
20	D	.30	
	t	1.25	
30	D	.30	
	t	1.30	
40	D	.0	
	t	.0	
50	D	.40	
	t	1.03	
60	D	.20	
	t	.44	
79	D	.40	
	t	.83	

NOTE: Positive difference between means indicates that pressure in the positions listed at the left exceeds that in positions listed at the top.

Examination of Table IV revealed that the strap pressure on the shoulder front for standing position with the low pack appears to be the same, for the same weight of pack, regardless of the plane on which the subject stood. Statistical analysis (Table V) supported this impression.

The strap pressure at the shoulder front with the high pack depended somewhat on the plane on which the subject stood. Examination of Table VI shows that, omitting data obtained with a 20-pound pack, pressure was the same for horizontal and upgrade planes. On the other hand, the pressure obtained when the subject faced downgrade was less than in standing on the horizontal or upgrade planes. The difference, however, was statistically significant only for certain loads.

Comparison of pressures obtained with low and high packs (Table VII) revealed that, with the exception of standing while facing downgrade,

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TABLE IV: PRESSURE (in pounds) OF PACK STRAPS ON FRONT OF SHOULDERS DURING STANDING

	Low Pack						High Pack					
	On a Horizontal Plane											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	2.3	3.2	4.3	5.3	6.0	6.7	2.0	3.4	4.3	5.1	6.1	6.9
Std. Deviation	1.0	1.1	1.3	1.5	1.9	1.8	1.1	1.0	1.3	1.2	1.4	1.6
Std. Error of Mean	.2	.2	.2	.3	.4	.3	.2	.2	.2	.2	.2	.3
	Facing Downgrade											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	2.3	3.2	4.1	5.0	5.8	6.6	2.2	3.1	3.8	4.6	5.5	6.2
Std. Deviation	.9	1.0	1.3	1.7	1.8	1.8	1.3	1.2	1.3	1.2	1.5	1.6
Std. Error of Mean	.1	.2	.2	.3	.3	.3	.3	.2	.2	.2	.3	.3
	Facing Upgrade											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	2.5	3.3	4.1	5.0	5.9	6.8	2.5	3.3	4.3	5.3	5.9	6.7
Std. Deviation	.8	.8	1.0	1.3	1.2	1.4	.9	1.0	1.1	1.7	1.7	2.0
Std. Error of Mean	.1	.1	.2	.2	.2	.2	.2	.2	.2	.3	.3	.3

COMPARISON OF PRESSURE EXERTED BY STRAPS OF LOW AND HIGH PACKS ON FRONT OF SHOULDERS DURING STANDING ON A HORIZONTAL PLANE OR FACING UPGRADE OR DOWNGRADE ON AN INCLINED PLANE

TABLE V: LOW PACK — TABLE VI: HIGH PACK

Pack Wt. (lbs.)	D = Difference between Means; t = t-ratio	Horizontal Plane	Down-grade	Pack Wt. (lbs.)	D = Difference between Means; t = t-ratio	Horizontal Plane	Down-grade
Upgrade							
20	D	.30	.20	20	D	.5	.30
	t	1.43	1.00		t	2.08*	1.11
30	D	.10	.10	30	D	.10	.90
	t	.45	.45		t	.42	.77
40	D	.20	.0	40	D	.0	.50
	t	.74	.0		t	.0	1.79*
50	D	.30	.0	50	D	.20	.70
	t	.91	.0		t	.57	2.06
60	D	.10	.10	60	D	-.20	.40
	t	.22	.28		t	.56	1.05
70	D	.10	.20	70	D	-.20	.50
	t	.26	.53		t	.48	1.16
Downgrade							
20	D	.0		20	D	.2	
	t	.0			t	.71	
30	D	.0		30	D	-.30	
	t	.0			t	1.15	
40	D	.10		40	D	-.5	
	t	.67			t	1.67	
50	D	.30		50	D	-.50	
	t	.79			t	1.79*	
60	D	.20		60	D	-.60	
	t	.40			t	1.76*	
70	D	.10		70	D	-.70	
	t	.23			t	1.84*	

*Indicates that difference between means, D, was statistically significant.

NOTE: Positive difference between means indicates that pressure in the positions listed at the left exceeds that in positions listed at the top.

more pressure was exerted by the high than by the low pack. The difference, however, was small and not statistically significant.

During downgrade standing, the low pack exerted more pressure than the high pack. For packs of 50 pounds or more, this became a definite trend, although the threshold of significance was not reached. This was true for both the pressure on the top and on the front of the shoulders.

It is evident, therefore, that in order to determine the strap pressure exerted by a pack while the subject is standing, it will suffice to measure strap pressure when he stands on a horizontal plane.

The relation between strap pressure and pack weight may be expressed by the following equations. These equations are applicable to both the low and the high pack.

Where x is pack weight in pounds and y is strap pressure in pounds.

Top of shoulder and clavicle

$$y = .149\ x \text{ or } y = .15\ x$$

Front of Shoulders

$$y = .4 + .09\ x \text{ or } y = .4 + .10\ x$$

These two equations are graphically presented in Figure 7.

b. <u>Strap pressure in walking</u>. It was found that, as in standing, pressure on the clavicle in walking was equal to that on the top of the shoulder. This was true for walking on horizontal, downgrade, and upgrade planes. For this reason, the data on clavicular pressure are not presented in this report. An exception to this rule was observed on one man with unusually prominent clavicles. In his case, the clavicular pressure was greater than that on the top of the shoulder. While this finding is of interest, it did not affect the general rule for the group.

The pertinent statistical data are presented in Tables VIII and IX. As in standing, the pressure on the top of the shoulder was greater than that on the front. Analysis showed that the pressure exerted by the low pack on the front of the shoulder was the same whether subjects walked on a horizontal plane or upgrade or downgrade (Table X). The same was true for the high pack (Table XI). Moreover, there was no statistically significant difference in the pressure exerted on the front of the shoulder by the high and low packs (Table XII).

As to strap pressure on the shoulder top with the low pack, there was a statistically significant difference between downgrade walking and walking on a horizontal plane. The pressure was greater in walking downgrade (Table XIII).

TABLE VII: COMPARISON OF PRESSURE EXERTED BY STRAPS OF HIGH AND LOW PACKS DURING STANDING ON A HORIZONTAL PLANE OR FACING UPGRADE OR DOWNGRADE ON AN INCLINED PLANE

Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Upgrade	Downgrade
Pressure on Shoulder Top				
20	D	-.30	-.20	.0
	t	1.10	.70	.17
30	D	-.40	-.30	.20
	t	1.62	.86	.68
40	D	.10	-.30	.10
	t	.19	.72	.32
50	D	-.10	-.20	.40
	t	.30	.42	1.01
60	D	.40	-.20	.60
	t	.61	.40	1.50
70	D	.30	.0	.80
	t	.56	.06	1.65
Pressure on Shoulder Front				
20	D	.30	.0	.10
	t	1.40	.0	.42
30	D	-.20	.0	.10
	t	.43	.21	.33
40	D	.0	-.20	.30
	t	.0	.88	.94
50	D	.20	-.30	.40
	t	.41	.94	1.58
60	D	-.10	.0	.30
	t	.11	.13	.85
70	D	-.20	.10	.40
	t	.39	.16	1.03

NOTE: Positive difference between means indicates that pressure while standing with the low pack was greater than pressure while standing with the high pack.

PRESSURE EXERTED BY THE STRAPS OF HIGH AND LOW PACKS ON TOP AND FRONT OF SHOULDERS DURING STANDING ON A HORIZONTAL PLANE

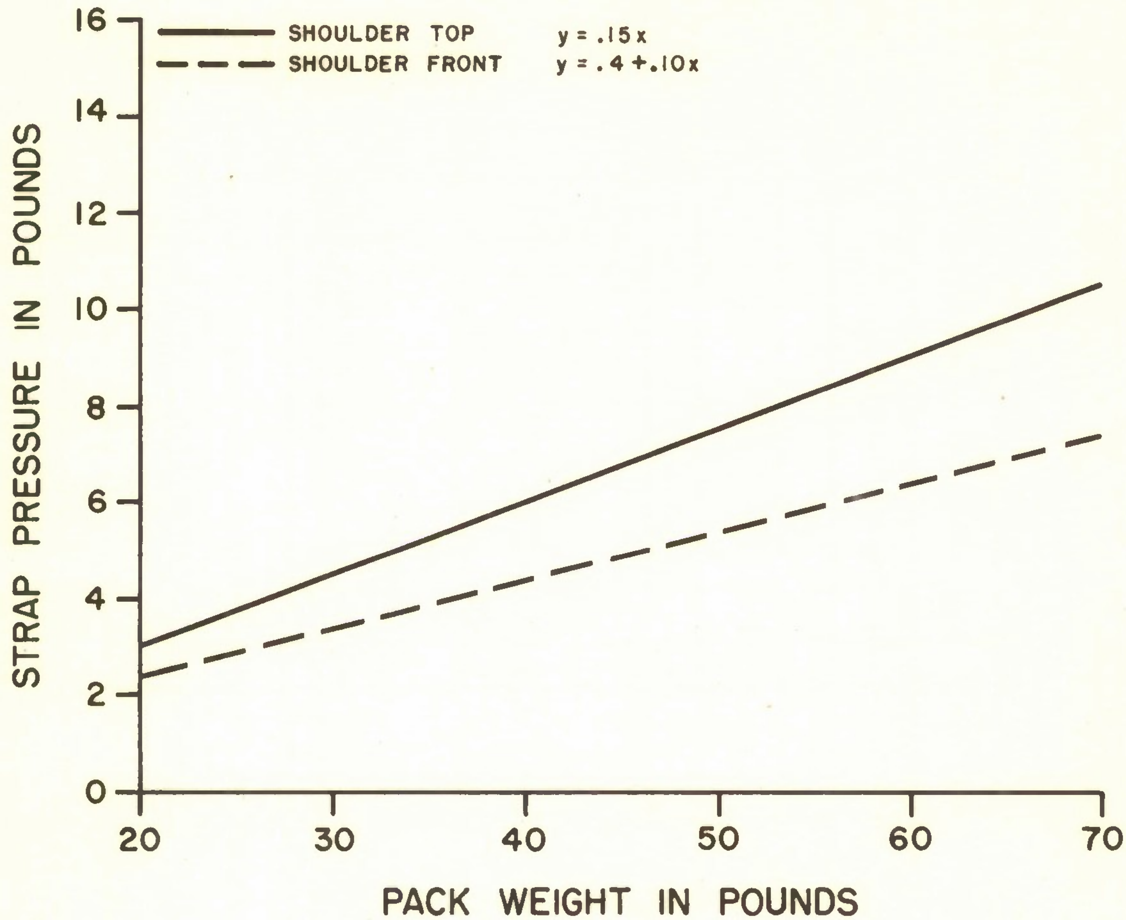

FIGURE 7

As far as strap pressure on the shoulder top was concerned, it was the same for the high pack, whether the subjects walked on a horizontal plane or upgrade or downgrade (Table XIV).

Comparison of strap pressures on the shoulder top, obtained with low and high packs, showed that they were the same in walking on horizontal and upgrade planes. In downgrade walking, the low pack exerted more pressure than the high pack. The difference was statistically significant for 60- and 70-pound loads (Table XII).

The formulas expressing the relationship of the strap pressure (y) during walking and the weight of the pack (x) are as follows:

	Shoulder Top	Shoulder Front
	High or Low Pack	
Horizontal Plane	$y = 1.8 + .196x$	$y = 1.5 + .121x$
Upgrade	$y = 2.3 + .173x$	$y = 1.5 + .121x$
	Low Pack	
Downgrade	$y = 1.8 + .196x$	$y = 1.5 + .121x$
	High Pack	
Downgrade	$y = 2.3 + .173x$	$y = 1.5 + .121x$

Figure 8 graphically presents a strap pressure-pack weight relationship for walking on a horizontal plane.

TABLE VIII: PRESSURE (in pounds) OF PACK STRAPS ON TOP OF SHOULDERS DURING WALKING

	Low Pack						High Pack					
	On a Horizontal Plane											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	5.2	6.9	8.8	10.9	12.2	13.9	5.3	7.1	9.0	10.5	12.2	13.8
Std. Deviation	1.5	1.9	2.3	2.6	3.1	2.9	1.4	1.7	2.6	2.5	2.9	2.8
Std. Error of Mean	.3	.3	.4	.4	.5	.5	.2	.3	.4	.4	.5	.5
	Downgrade											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	5.8	7.7	9.7	11.8	13.6	15.5	5.8	7.6	9.4	11.1	12.7	14.5
Std. Deviation	1.7	1.6	1.9	2.1	2.1	2.4	1.3	1.5	2.0	2.1	2.0	2.2
Std. Error of Mean	.3	.3	.3	.4	.3	.4	.2	.3	.3	.4	.3	.4
	Upgrade											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	5.5	7.3	9.2	11.4	13.1	14.8	5.6	7.5	9.5	11.3	13.3	14.5
Std. Deviation	1.6	2.1	2.3	3.2	3.4	3.4	1.4	1.9	2.3	2.8	2.7	3.2
Std. Error of Mean	.3	.3	.4	.5	.6	.6	.2	.3	.4	.5	.4	.5

TABLE IX: PRESSURE (in pounds) OF PACK STRAPS ON FRONT OF SHOULDERS DURING WALKING

	Low Pack						High Pack					
	On a Horizontal Plane											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	3.7	5.2	6.3	7.5	8.5	9.6	4.0	5.3	6.4	7.6	8.7	9.8
Std. Deviation	1.0	1.4	1.6	1.8	1.9	2.3	1.2	1.4	1.5	1.6	1.9	2.7
Std. Error of Mean	.2	.2	.3	.3	.3	.4	.2	.2	.3	.3	.3	.3
	Downgrade											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	3.9	5.1	6.2	7.6	8.8	10.0	3.9	5.0	6.2	7.2	8.5	9.6
Std. Deviation	1.2	1.6	1.8	2.1	2.4	2.5	1.4	1.6	1.7	1.9	2.3	2.2
Std. Error of Mean	.2	.3	.3	.4	.4	.4	.2	.3	.3	.3	.4	.4
	Upgrade											
Weight of Load (pounds)	20	30	40	50	60	70	20	30	40	50	60	70
Mean	3.6	4.8	6.0	7.1	8.3	9.4	3.7	5.0	6.3	7.3	8.5	9.3
Std. Deviation	.9	1.1	1.4	1.6	1.9	2.2	1.2	1.7	1.9	2.1	2.4	2.9
Std. Error of Mean	.2	.2	.2	.3	.3	.4	.2	.3	.3	.3	.4	.5

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c. Relation between strap pressure and anthropometric measurements of the chest and shoulder.* The anthropometric data are presented in Table XV. Analysis of the data reveals that coefficients of correlation among the anthropometric measurements and strap pressure were low (Table XVI). The highest were between the chest circumference and the shoulder circumference, on one hand, and the strap pressure on the shoulder front, when the subject was standing with the high pack, on the other hand. Coefficients of correlation among the anthropometric measurements themselves were also calculated (Table XVII). Correlation was high

*This part of the study was done by a Springfield College graduate student, I.F. Sclar.

COMPARISON OF PRESSURE EXERTED BY STRAPS OF LOW AND HIGH PACKS ON FRONT OF SHOULDERS DURING WALKING ON A HORIZONTAL PLANE OR UPGRADE OR DOWNGRADE

TABLE X: LOW PACK

Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Down-grade
	Upgrade		
20	D	.10	.30
	t	.45	1.15
30	D	.40	.40
	t	1.38	1.21
40	D	.30	.20
	t	.86	.53
50	D	.40	.50
	t	1.00	1.14
60	D	.20	.50
	t	.44	.98
70	D	.20	.60
	t	.38	1.09
	Downgrade		
20	D	.20	
	t	.77	
30	D	.10	
	t	.29	
40	D	.10	
	t	.25	
50	D	.10	
	t	.22	
60	D	.30	
	t	.55	
70	D	.40	
	t	.71	

TABLE XI: HIGH PACK

Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Down-grade
	Upgrade		
20	D	-.30	.20
	t	1.07	.65
30	D	.30	.0
	t	.81	.0
40	D	.10	.10
	t	.24	.23
50	D	.30	.10
	t	.70	.22
60	D	.20	.0
	t	.39	.0
70	D	.50	.30
	t	.83	.49
	Downgrade		
20	D	.10	
	t	.32	
30	D	.30	
	t	.83	
40	D	.20	
	t	.53	
50	D	.40	
	t	.98	
60	D	.20	
	t	.40	
70	D	.20	
	t	.39	

NOTE: Positive difference between means indicates that pressure in the positions listed at the left exceeds that while walking as listed at the top.

TABLE XII: COMPARISON OF PRESSURE EXERTED BY STRAPS OF HIGH AND LOW PACKS DURING WALKING ON A HORIZONTAL PLANE OR UPGRADE OR DOWNGRADE

Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Upgrade	Downgrade
Pressure on Shoulder Top				
20	D	-.3	-.1	.0
	t	.38	.25	.05
30	D	-.2	-.2	.1
	t	.45	.50	.25
40	D	-.2	-.3	.3
	t	.26	.47	.56
50	D	.4	.1	.7
	t	.63	.20	1.36
60	D	.0	-.2	.9
	t	.08	.18	1.90*
70	D	.1	.3	1.0
	t	.31	.18	1.84*
Pressure on Shoulder Front				
20	D	-.3	-.1	.0
	t	.92	.22	.07
30	D	-.1	-.2	.1
	t	.25	.46	.18
40	D	-.1	-.3	.0
	t	.29	.82	.00
50	D	-.1	-.2	.4
	t	.4	.51	.89
60	D	-.2	-.2	.3
	t	.64	.39	.60
70	D	-.2	.1	.4
	t	.56	.18	.79

*Indicates that difference between means, D, was statistically significant.

NOTE: Positive difference between means indicates that pressure while walking with the low pack was greater than pressure while walking with the high pack.

COMPARISON OF PRESSURE EXERTED BY STRAPS OF LOW AND HIGH PACKS ON TOP OF SHOULDERS DURING WALKING ON A HORIZONTAL PLANE OR UPGRADE OR DOWNGRADE

TABLE XIII: LOW PACK — TABLE XIV: HIGH PACK

Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Down-grade	Pack Wt. (lbs.)	D = Difference between Means t = t-ratio	Horizontal Plane	Down-grade
Upgrade							
20	D t	.30 .81	.30 .77	20	D t	.30 .88	.20 .63
30	D t	.40 .85	.40 .91	30	D t	.40 .95	.10 .25
40	D t	.40 .74	.50 1.02	40	D t	.50 .88	.10 .17
50	D t	.50 .74	.40 .63	50	D t	.80 1.27	.20 .34
60	D t	.90 1.17	.50 .75	60	D t	1.10 1.67	.60 1.07
70	D t	.90 1.22	.70 1.01	70	D t	.70 .99	.0 .0
Downgrade							
20	D t	.60 1.54		20	D t	.50 1.52	
30	D t	.80 1.95*		30	D t	.50 1.32	
40	D t	.90 1.53		40	D t	.40 .74	
50	D t	.90 1.67		50	D t	.60 1.09	
60	D t	1.40 2.22*		60	D t	.50 .85	
70	D t	1.66 2.58*		70	D t	.70 1.17	

*Indicates that difference between means, D, was statistically significant.

NOTE: Positive difference between means indicates that pressure while walking as listed at the left exceeds that while walking as listed at the top.

PRESSURE EXERTED BY THE STRAPS OF HIGH AND LOW PACKS ON TOP AND FRONT OF SHOULDERS DURING WALKING ON A HORIZONTAL PLANE

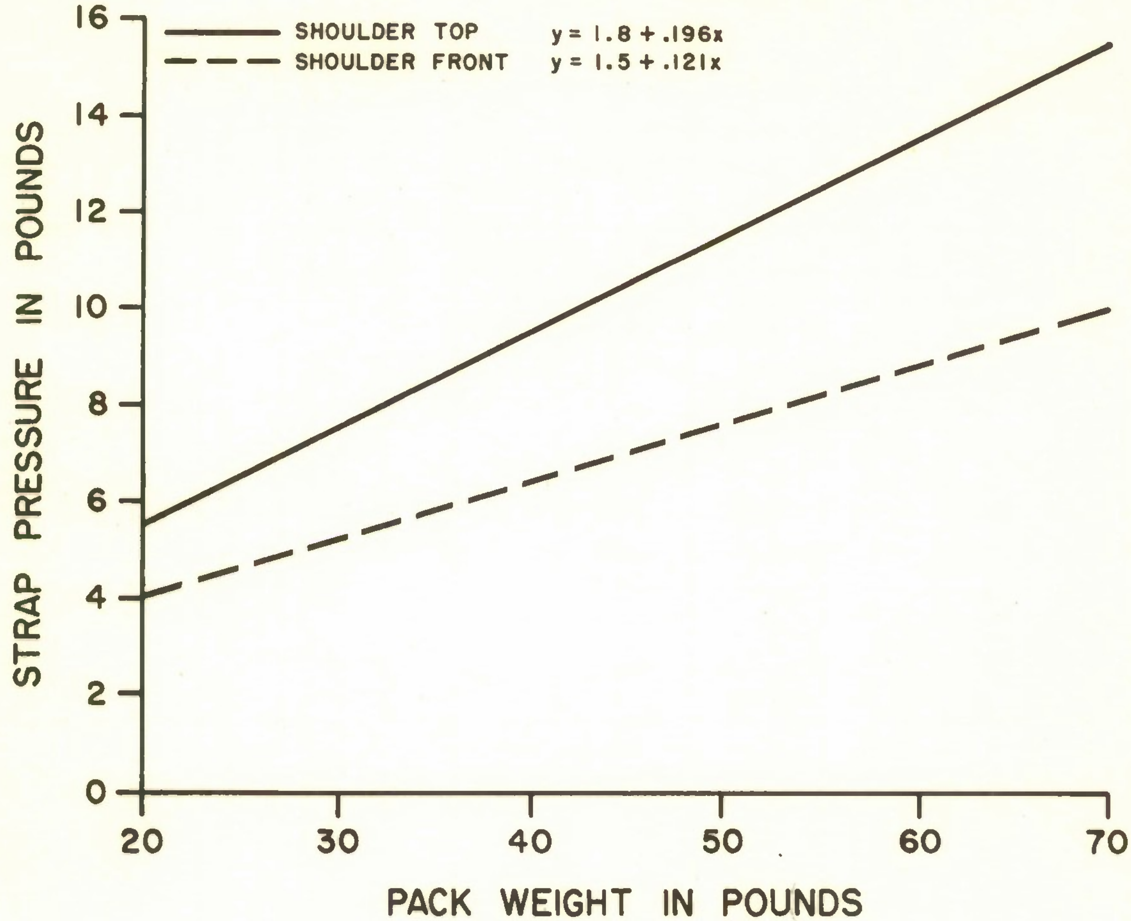

FIGURE 8

between the chest width and chest circumference; however, the correlation was also high between chest width and shoulder circumference. The lowest correlation was between sternal length and chest depth.

4. Discussion

a. It is a common observation that most people prefer a high pack to a low one because "it feels more comfortable." Attempts have been made to find an objective basis for this preference. Daniels, et al have shown that there is little or no difference in energy expenditure

TABLE XV: ANTHROPOMETRIC MEASUREMENTS OBTAINED ON 49 SUBJECTS

Measurement	Range	Mean	Standard Deviation	Standard Error
	cm.	cm.		
Bi-Acromial Diameter	35-48	40.9	2.37	.34
Chest Width	26-39	31.4	2.65	.38
Sternal Length	15-24	19.3	1.97	.28
Chest Depth	16-28	21.1	2.22	.32
Chest Circumference	82-127	99.3	8.36	1.19
Shoulder Circumference	36.5-55.5	44.1	3.20	.50
Body-Strap Contact, High Pack	25-49.5	30.4	3.82	.55
Body-Strap Contact, Low Pack	24.5-44	29.7	3.06	.44

when carrying the high or the low pack.*

The present investigation reveals that strap pressure for the high and the low pack is the same except when the bearer is walking downgrade. At this time the low pack pressure becomes greater than that of the high pack. Even while standing still, facing downgrade, strap pressure for low packs becomes almost significantly higher than that exerted by the high pack. Therefore, on the basis of the present investigation, it is possible to explain a preference for the high pack (of 50 or more pounds) instead of the low one, when a person is walking downgrade.

It may thus be said that strap pressure is not the deciding factor in the choice of the pack position, when the bearer walks either upgrade or on a horizontal plane. It may also be that the high pack requires a lesser angle of forward inclination of the trunk and, therefore, causes

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*Daniels, F., Jr., J.H. Vanderbie and C.L. Bommarito. Energy cost of carrying three load distributions on a treadmill. OQMG. EPB Rpt. No. 203, March 1953.

less local muscular fatigue. This latter supposition is now being investigated at Springfield College.

b. The strap pressure at all points is higher during walking than during standing. This increase in pressure is the result of a jar caused by each step. The continuous record of strap pressure during walking is not a straight line, but is sinusoidal. It may be of interest to investigate these changes in pressure by means of a recording manometer. Since strap pressure during standing still and walking differs in magnitude, it is possible to test a man while he is standing still and predict the effect during walking.

c. The pressure meter described in this report can be conveniently used for testing improvements in the pack: the type and size of straps, strap padding, and the distribution of weight in the pack.

TABLE XVI: CORRELATIONS BETWEEN STRAP PRESSURES AND CERTAIN ANTHROPOMETRIC MEASURES DURING STANDING AND WALKING ON A HORIZONTAL PLANE

Measures	Strap Pressures							
	Standing				Walking			
	High Pack		Low Pack		High Pack		Low Pack	
	S.T.	S.F.	S.T.	S.F.	S.T.	S.F.	S.T.	S.F.
Bi-Acromial Diameter	.0162	.1325	-.2096	.3080*	.0564	.1931	-.1838	.2821*
Chest Width	-.0747	.3396*	-.3692*	.1802	-.1647	.3728*	-.3539*	.1938
Sternal Length	-.1184	.0774	-.3819*	.0894	-.2091	.1835	-.3194*	.1669
Chest Depth	.1295	.2834*	-.2094	.1720	.0803	.2527	-.2629	.1886
Chest Circumference	-.1725	.4176*	-.3599*	.2652	-.1300	.3909*	-.4082*	.2536
Shoulder Circumference	-.0522	.4308*	-.3605*	.1070	-.1349	.3722*	-.3768*	.1202
Body-Strap Contact	.0753	.0325	-.2284	.0868	-.0331	.0756	-.2330	.1300

*Indicates statistical significance at the .05 level.

S.T. - Shoulder Top
S.F. - Shoulder Front

TABLE XVII: INTERCORRELATIONS OF ANTHROPOMETRIC MEASURES

Measures	1 Bi-Acromial Diameter	2 Chest Width	3 Sternal Length	4 Chest Depth	5 Chest Circumference	6 Shoulder Circumference	7 Body-Strap Contact High Pack	8 Body-Strap Contact Low Pack
1. Bi-Acromial Diameter		.5772	.4898	.3310	.4953	.4910	.5671	.6157
2. Chest Width			.5539	.6465	.9175	.8389	.7339	.7397
3. Sternal Length				.2984	.5345	.4745	.5053	.4785
4. Chest Depth					.7732	.6369	.6026	.6044
5. Chest Circumference						.8745	.7458	.7483
6. Shoulder Circumference							.7393	.7467
7. Body-Strap Contact, High Pack								.9481
8. Body-Strap Contact Low Pack								

d. Because the strap pressure meter is portable, it is possible to use it while the pack carrier is walking outdoors. The investigator can carry the meter in his hand and take readings while walking. An observer can record the readings.

e. The practicability of the pressure meter was demonstrated when it was used to compare different packs. The strap pressure exerted by an experimental combat-cargo pack was compared with that caused by a low pack carried on a packboard. Both packs weighed 40 pounds and were tested on ten men while standing and walking. The results are given in Table XVIII. In this table, it is shown that the experimental pack definitely caused less pressure on the top of the shoulder. As to the pressure on the front of the shoulder, the experimental pack caused less pressure in walking on a horizontal plane. In walking upgrade or downgrade, the experimental pack caused more pressure. Thus, it is apparent the experimental pack needs further study.

In a field exercise with the experimental pack, one subject observed that the pack seemed to be heavier when the waist strap was unbuckled. Tests with the pressure meter showed that the subject was right. It may be asked: "What is the use of an instrument when a man can feel the pressure and, therefore, judge as to its amount?" Of course,

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TABLE XVIII: COMPARISON OF STRAP PRESSURE EXERTED BY AN EXPERIMENTAL COMBAT-CARGO PACK AND BY LOW AND HIGH PACKS CARRIED ON A PACKBOARD

(Pressure in Pounds)

Activity	Experimental Pack	Pack on a Packboard Low	Pack on a Packboard High
Shoulder Top			
Walking,			
Horizontal	8.66	10.13	10.29
Upgrade	8.23	9.99	10.58
Downgrade	10.29	11.03	9.99
Shoulder Front			
Walking,			
Horizontal	4.40	6.43	7.24
Upgrade	5.89	5.39	5.18
Downgrade	6.13	5.65	4.82

NOTE: Both packs weighed 40 pounds.

a man can feel the pressure, but his judgment as to the actual amount of pressure being exerted is not reliable. The same strap pressure, after a period of walking, feels much greater than it does at first. Moreover, the sensitivity of a man may sometimes depend more upon his morale than his physical stamina. This fact may account for some apparent discrepancies. Whereas a man, physically strong but weak in spirit, may constantly gripe that the pack is "killing him," another man, physically weaker, may carry a similar pack without complaint.

f. The pressure meter measures the pressure across the strap in an area approximately the width of the pressure chamber. It is true that, when the pressure was measured over the top and front of the shoulder, the pressure chamber was not placed perpendicular to the strap, but somewhat obliquely. When the pressure chamber was placed at an equal angle in the calibrating device and calibrated, the manometer readings were the same as when the pressure chamber was placed squarely under the strap. Evidently, the area of the pressure chamber under the strap is not materially affected by the small angle when pressure on the top and the front of the shoulder is measured.

g. The investigators expected that, with each additional load placed in the pack, the increment of strap pressure would decrease. This supposition was based on the observation that, with each additional weight, the body leaned farther forward and, therefore, a lesser pull on the straps could be expected. Experiments, however, showed that, at least up to 70 pounds of load, the proportionality between the strap pressure and the weight of the pack remained constant (Figures 7 and 8).

Incidentally, the strap pressure is affected even by respiratory movements of the chest. During an inspiration, the chest expands and causes an increase in strap pressure.

5. Summary

a. Measurement of pressure. The pressure exerted by pack straps on the top of the shoulder, the clavicle, and the front of the shoulder was measured on 37 male college students carrying packs weighing from 20 to 70 pounds, in both the high and low positions. This pressure was measured while the subjects stood still and also while they walked on a motor-driven treadmill at a speed of 2.8 mph.

b. Pressure meter. Strap pressure was measured by means of a device called a pressure meter, consisting of an aneroid sphygmomanometer and a pressure chamber calibrated in such a way that readings in millimeters from the manometer could be translated into pounds of strap pressure. This pressure meter can be used not only in the laboratory but while the subject walks outdoors. A series of tests made by two investigators had coefficients of correlation of "r" = +.93 during standing and "r" = +.96 during walking, indicating that the objectivity of this method is high.

c. Strap pressure in standing. Strap pressure on the top of the shoulder is greater than that on the front of the shoulder, while pressure on the clavicle is equal to pressure on the shoulder top. The strap pressure in pounds on the top of the shoulder or on the clavicle may be expressed as $y = .15x$, where y is the strap pressure in pounds, and x is the pack weight. For example, the strap pressure for the 20-pound pack is three pounds and for a 70-pound pack it is 10.5 pounds. The strap pressure on the shoulder front is $y = .4 + .10x$. Thus, for a pack weighing 20 pounds, this pressure is 2.4 pounds; for a pack of 70 pounds, it is 7.4 pounds. The strap pressure on the top or the front of the shoulder is not affected by the nine-degree angle of inclination of the plane on which the subject stands. There is no difference in strap pressure between the low and high pack.

d. Strap pressure in walking. The pressure on the top of the shoulder is equal to that on the clavicle, but is greater than the pressure on the front of the shoulder. The relation between the strap pressure in pounds (y) and the weight of the pack (x) may be expressed by the following formulas:

	Shoulder Top	Shoulder Front
	High or Low Pack	
Horizontal Plane	$y = 1.8 + .19x$	$y = 1.5 + .121x$
Upgrade	$y = 2.3 + .173x$	$y = 1.5 + .121x$
	Downgrade	
Low Pack	$y = 1.8 + .196x$	$y = 1.5 + .121x$
High Pack	$y = 2.3 + .173x$	$y = 1.5 + .121x$

e. Relation between chest size and strap pressure. In general, with increase in chest size, the strap pressure on the shoulder top decreases, while that on the shoulder front increases.

f. The use of the strap pressure measurement for evaluation of new designs of packs. By means of a pressure meter the strap pressure exerted by an experimental pack can be easily found, even without laboratory facilities, and compared with the pressure exerted by the old packs.

6. Conclusions

a. Measurement of strap pressure is the only objective quantitative evaluation of this pressure. Subjective reports are difficult to evaluate and often impossible to compare.

b. It is sufficient to measure the strap pressure at two points only: the shoulder top and the shoulder front.

c. A pressure measurement during standing gives an estimate of pressure during walking.

d. Strap pressure on the shoulder front increases with the increase either in chest size or shoulder circumference while at the same time, the pressure on the top of the shoulder decreases.

7. Recommendation

That designers of new packs use the pressure meter and test strap pressure in order to determine objectively the strap pressure characteristics of the pack, rather than to rely on subjective reports obtained during field studies.

8. Acknowledgments

The assistance rendered by Mrs. L.M. Ewing, Messrs. D.A. Dome and L.B. Rowell of Springfield College is gratefully acknowledged.

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